The Institute of Physics
BULLETIN
DECEMBER 1956 · VOL. 7 · No. 12

CONTENTS

NOTICES TO MEMBERS
Page 313

WHAT DOES RELATIVITY MEAN
PROFESSOR HERBERT DINGLE
Page 314

FORTHCOMING INSTITUTE MEETINGS
Page 323

PHYSICS AND GENERAL EDUCATION
NORMAN CLARKE
Page 324

THE PARSONS AND MARINE ENGINEERING TURBINE RESEARCH AND DEVELOPMENT ASSOCIATION
T. W. F. BROWN
Page 333

THE INSTITUTE'S JOURNALS
Page 339

INDEX TO VOLUME 7
Page 342

The Bulletin is published by The Institute of Physics for circulation to its members.

Notices to Members

Conference on Degree and Diploma Courses in Applied Physics

The conference on "Degree and Diploma Courses in Applied Physics" that was arranged jointly with the London and Home Counties Regional Advisory Council for Higher Technological Education was held at The Institution of Electrical Engineers on November 15 and 16. The attendance was 158, more than half of whom were from industry or government service. The general opinion appears to be that the conference was very successful. A full record of the addresses and discussion was taken and will be published in the *Bulletin*. Publication will probably be over three months beginning in January or February next. Copies of the report will later be published in booklet form; a copy will be sent to all who attended the conference and others will be available for general sale.

Emolument Inquiry

About 2,500 Fellows, Associates and Graduates returned cards for the recent emolument inquiry. It is hoped to be able to publish a report in the January issue of the *Bulletin*.

Meeting on "The Shortage of Physicists"

The Liverpool and North Wales branch has arranged a one day meeting on "The Shortage of Physicists" to be held at the University of Liverpool on Saturday, January 19. Full details may be obtained from Professor J. D. Craggs, Honorary Secretary of the Liverpool and North Wales branch, or from the Deputy Secretary of the Institute.

What Does Relativity Mean?*

By Professor HERBERT DINGLE, D.Sc.

(*Emeritus Professor of History and Philosophy of Science, University College, London*)

A RECENT discussion in *Nature*** has raised again the old problem of the clock paradox. A traveller moves at high speed to a star and returns. Owing to the "relativistic contraction of time," the journey takes a shorter time for him than for the inhabitants of the Earth, so that he returns in all respects younger than he would have been had he stayed at home. Notwithstanding that the "relativistic contraction of time" is dependent on the postulate that motion is essentially relative—implying that it is equally true to say that the "traveller" has remained at rest and the Earth has been in motion, in which case the relative ages of the parties would be reversed—this has been widely believed, and startling conclusions have been drawn.

Until recently the paradox was merely a pleasant puzzle, providing material for an agreeable Common Room discussion, but it has now taken on a more serious aspect. Space travel at high velocities, if not yet a possibility, is being seriously discussed, and extremely bizarre consequences are foreshadowed. At the seventh International Astronautical Congress, held in Rome in September last, Professor G. A. Crocco, President of the Italian Rocket Society, is reported† to have said that "while centuries passed by travellers would experience only the passage of minutes and would become 'almost immortal'." The chief German delegate, Professor Sanger, seems to have added further detail.‡ "The terrestrial years would pass like seconds for the members of the crew, who could fly for years without growing a day older. The shock to the rocket flyers would come on their return to earth. They would find their wives and friends had died and their children grown old during a voyage which to them had seemingly taken only a few days."

The seeds are here of dangerous illusions when such travel comes closer to practical politics; but that is not the worst. The correspondence arising from the discussion in *Nature* has revealed a truly alarming state of affairs. The otherwise incredible fact emerges that physicists of distinction—men holding high positions in universities and research laboratories—so completely misunderstand the theory of relativity as to think that it does, in fact, entail these fantastic consequences. The special theory of relativity is now almost an everyday instrument of advanced physical research, and projects based on its requirements are being put into operation which may have the gravest results for the world if they are not soundly based. One need not be a scaremonger to assert that a situation in which the material destiny of the world is in the hands of men manipulating a tool whose nature they quite misconceive is one of extreme peril. That, however, is the situation in which we now stand, and no apology is offered for making a fresh attempt to expose the true nature of this theory, of which there was already a surfeit of explanations—largely futile as it turns out—a generation ago.

The whole theory of relativity, special and general theory alike, is based on the postulate that motion is a relative phenomenon. What does this mean? To take the simplest case—that of only two bodies in an otherwise empty universe—it means that a statement that they are in motion has significance only if one is moving relatively to the other. The possibility that they are both moving equally is not to be entertained, because such a state would be indistinguishable from one in which they are both at rest and from one in which they

* Based on a lecture given to the Liverpool and North Wales Branch of the Institute on November 15, 1956.

** *Nature*, **177**, 782; **178**, 680 (1956)

† *The Times*, September 19, 1956

‡ *The Sunday Times*, September 23, 1956

are both moving with any other velocity at all than the one supposed. *Relative* motion, however—the motion of one with respect to the other—is an actual physical phenomenon having definite observable effects. But this motion is not something that belongs to either of them ; it is something that concerns only the relation between them. We can say if we like that A is at rest and B moving, or that B is at rest and A moving, or that they share the motion in any way we please so long as the relative motion is not altered. All these statements are equally true or equally false. Strictly speaking, they are equally false, because literally they assert that a single body possesses motion, but with proper safeguards we can use them for convenience without falling into error. In a system of more than two bodies the same thing is true, but the situation is more complicated of course. The relative motion of any two of them is a relation between those two, and we may, if we please, assume any one of the bodies in the system to be at rest or to have any motion we care to assign to it, provided that the relative motion of each pair remains unaltered.

It follows inevitably from this that motion (uniform motion if the special theory of relativity be accepted, and any motion at all if the general theory be accepted) cannot possibly affect a body in any way, for if it did we would have to assign that effect to the motion of that body, and there is no such thing as the motion of that body. Hence the conclusion is inescapable that when the space traveller returns, his clock, and everything about him that could be used as a time recorder, will (apart, of course, from accidents and effects of influences other than motion) show the lapse of exactly the same time as the corresponding recorders of the stay-at-home. For if there were a difference, one of the bodies would have to have been affected by the motion, and whichever that may be supposed to have been may be supposed to have remained at rest and the effect would have happened without a cause. That is the whole solution of the problem. It is clearly unanswerable by anyone who accepts the principle of relativity.

Since, however, it is not universally accepted, we must infer that there is some failure to appreciate the fact that motion is entirely a relation between bodies and not a characteristic of either or both of them. To show that this is indeed a fact I will take one example—the Doppler effect—which is one of the best known and most widely applied consequences of the relativity of motion. Consider three identical sources of monochromatic light, A, B and C, lying in the same straight line with B between A and C. At first let them all be at rest. Then an observer standing by B sees that all three emit light of the same wavelength. Now let B move towards A, and therefore away from C. (It does not matter, of course, whether we say that B is moving and A and C at rest, or that A and C are moving and B is at rest, but since some *Nature* correspondents seem to think this difference important, let us assume that B is given a sudden impulse which is quickly removed, after which it moves with constant velocity.) Our observer, still keeping abreast of B, then sees that the wavelength of the light from A is less, and that of the light from C is greater, than the wavelength of the light from B, and he must associate this change with the motion because it can be destroyed and started again *ad lib*, as the motion is destroyed and started again. Here, then, is a definite observable physical change caused by motion.

But it is not a change in any of the sources of light, A, B and C. It is not a change in B, the body moved, for if it were the wavelength of the light from both A and C would be increased or decreased equally, whereas one is decreased and the other increased. Likewise it is not a change in A and C, or we would have to suppose that an impulse given to B had no effect on B but somehow changed A and C in opposite directions. The latter possibility is hardly to be entertained, but lest in desperation it be grasped at, let us suppose that a fourth source, D, identical with the others, is originally adjacent to B but is not given the impulse which moves B. Then an observer standing by it sees that neither A nor C has been changed by the motion of B, and we cannot suppose that D has suffered a compensating change, for no

change in it could compensate at the same time for the assumed opposite changes in A and C. There is no alternative, then, to the conclusion that the relative wavelengths of the light from the three sources have changed without any change taking place in the light from any one of them. And since the change is due to motion, it follows that the relative motion of the bodies is something that concerns the relation between them but does not belong to any one of them individually.

To physicists saturated with the notion that physics was the study of the material world, this conclusion (reached, of course, not through the Doppler effect but through other phenomena, but nevertheless the same conclusion) when first reached, was inconceivable. They could not imagine that a change could occur in the relation between two bodies when neither of the bodies had itself changed in any way, so they set themselves to avoid such an " absurdity " by a succession of ingenious devices. The menace of the Doppler effect had already been removed by the invention of an unobservable material—the ether—existing between the bodies, which could be supposed to suffer the change and so restore faith in a material basis for all phenomena, but the requirements of the special theory of relativity—that space intervals and time intervals were functions of a velocity which could be created or destroyed by taking thought—not only took away this illusion but also appeared to leave no loophole of escape from the admission that even ordinary everyday physical phenomena were not explicable wholly in terms of changes occurring in material bodies. The *res cogitans* and *res extensa* of Descartes, whose essential distinction had been a presupposition of physics for nearly 300 years, seemed to have become hopelessly confused, and physicists were utterly at sea.

Probably the earliest man in this country to perceive the full implications of the theory of relativity was Eddington, and the tragedy was that he who, above all others at that time, was capable of steering physics along the right course, deferred to prejudices that should have been wholly abjured and acquiesced in illusions that should have been utterly renounced. How well he understood the matter is shown by his first exposition of the subject, from which most English-speaking relativists of the time acquired their knowledge of it. In his Report to The Physical Society in 1918* he wrote : " When a rod is started from rest into uniform motion, nothing whatever happens to the rod. We say that it contracts ; but length is not a property of the rod ; it is a *relation* between the rod and the observer. Until the observer is specified the length of the rod is quite indeterminate. We ought always to remember that our experiments reveal only relations, and not properties inherent in individual objects ; and then the correspondence of two systems, differing only in uniform motion, becomes axiomatic, so that laborious mathematical verifications are redundant." Nothing could be more positive. But then came the fall. He proceeded : " Human minds being what they are, that is a counsel of perfection, and we shall not follow it too strictly."

It was a fatal error. Human minds being what they are, it should have been followed with the most relentless strictness. Instead, physicists were given a license for supposing that the rod did literally contract, and they seized it avidly. The theory of relativity, accepted in name, was converted back into the " FitzGerald contraction," with which in fact it is (except for the mathematical expression) fundamentally inconsistent. The " time retardation " was similarly ascribed to a physical change occurring in a clock, and physics, once more propped up on the old winded, spavined horse, proceeded blindly towards an ultimate unavoidable catastrophe with no one having the vision even to say : "Apres nous le deluge." Eddington succeeded in deceiving even himself, and in his later work sometimes forgot what he had once seen to be " axiomatic." Such is the danger of compromise.

And yet there was nothing whatever of fundamental difficulty, or even of fundamental novelty, in relativity. We had been accustomed to it in a closely related matter

* *Report on the Relativity Theory of Gravitation*, pp. 8–9

for centuries, and had recognized as quite natural all the implications that in the relativity of motion seemed so incredible. There was a time when it was believed that there were absolute positions in nature. The Earth was the centre of the universe, and other places had properties which were absolutely determined by their positions with relation to it. When Copernicus asserted the mobility of the Earth, he had no thought of denying the significance of the centre ; he placed the Sun there instead. Bruno appears to have been the first to realize that the universe had no distinguishable places but that any object in it could be regarded as at its centre, and the idea was so unpopular that he was burnt for it. But it was not long before this became an axiom of all serious thinking, and no one for a very long time has found it incomprehensible. Yet all the supposed anomalies of the relativity of motion are exhibited also by the relativity of position.

Corresponding to our three sources of light, let us imagine three objects—say three metre rods, A′, B′, C′, to fix our ideas—situated at first in the same place, corresponding to the sources of light having the same motion. To an observer standing, say, 10 metres away, they appear exactly alike. Now let their relative positions change so that B′ is still 10 metres, C′ is one metre, and A′ is 100 metres from the observer. Then C′ appears larger, A′ smaller, and B′ the same size as before. Moreover, C′ shows more detail, and A′ less, than B′, and C′ obscures objects previously seen behind it while other objects, previously obscured by A′, now come into view. These are undoubted phenomena, actual, undeniable physical changes, and by a precisely similar argument to that used with the light sources we can prove that none of the rods has itself changed. But in fact no one is likely to suppose that it has. In this case we immediately recognize that the differences that have come into existence between the rods belong only to their *relations* with one another, while they themselves have remained exactly the same. Moreover, these differences are of just the same character as the differences in the wavelengths of our light. An observer beside the source C would say that the source B was reddened, whereas the B observer would make the same charge against C, and similarly the " FitzGerald contraction " would be assigned by C to B and by B to C. Correspondingly, an observer one metre from B′ would say that B′ had become larger and C′ remained the same size. The phenomena are precisely equivalent, and they show that there is intrinsically no difficulty whatever in conceiving of changes arising from a relation between bodies which have themselves remained unchanged.

How have we dealt with this phenomenon of relativity of position ? We have recognized that whenever we are concerned with a body in relation to an external point of view, whenever its position with relation to other bodies has to be taken into account, the *effective* length of the body is not l, the quantity we get by measuring it in the ordinary way, but l/d, where d is the distance between the body and the point of view. That is the quantity that enables us to calculate the phenomena we will observe in any given situation. Thus, although l for the Sun's diameter is admitted to be many times greater than l for the Moon's diameter, we have no difficulty in understanding that an earthbound observer can observe the Moon eclipsing the Sun, for l/d for the Moon may be greater than the corresponding quantity for the Sun when d is measured from the Earth. In fact, when the *Nautical Almanac* gives the data for calculating the circumstances of a solar eclipse, it does not mention l or d in either case, but gives only l/d for the two bodies, as though those quantities were actual measures of their sizes. But we do not make the mistake of supposing that the Moon is actually bigger than the Sun. We understand clearly the difference between the two quantities l and d. The one is concerned only with an *intrinsic quality* of the Sun or Moon, the other only with the *relation* between that body and the point of view adopted. We recognize the necessity of taking both into account whenever the bodies are seen from an external point of view, but we are in no danger of supposing that the total expression, l/d, measures any intrinsic quality of the body concerned.

Exactly the same device is adopted by the theory of relativity in dealing with the relative *motions* of bodies. The problems here are rather more complex because we have chosen to measure velocity in terms of two quantities, time and space, instead of a single one, but that is unimportant. Just as with the relativity of position, we postulate that whenever a body is to be considered in relation to an external standard of rest—i.e. whenever it has a finite velocity, V, with respect to such a standard—the *effective* length of the body is la, and the *effective* time of any periodic change associated with it is ta, where l and t are the intrinsic values of the length and period, measured with respect to a standard at rest relatively to the body, and $a = (1 - V^2/c^2)^{\frac{1}{2}}$. The distinction between l (or t) and a is perfectly sharp and clear. The former is an intrinsic characteristic of the body ; the latter can be varied at will by changing the standard with respect to which the motion of the body is estimated. a is the precise analogue of d in the relativity of position.

As soon as this is realized the problem of the space-traveller ceases to be a problem. Having once been started, he and his clock go their way, tread out their measure, exactly as though there were no speck of matter far off on which someone was deciding what speed it was convenient to ascribe to them. To suppose that when the traveller returns he brings with him the effect of the factor a, which from the earthly point of view is significant during his journey, is equivalent to supposing that when our metre rod A′ is brought back from 100 metres to 10 metres from the observer, it will bring back its diminished size and appear smaller than B′. But if the true meaning of the factor a is *not* realized—in particular, if it is supposed to indicate an actual change in the body to whose measure it is applied—all sorts of queer deductions are possible. The Lorentz transformation, which is the generalized form in which the relativity postulate is applied, is a potent source of illusions, for it is fatally easy to misapply. I have found many such fallacies, and there is every indication that the list is not yet exhausted. But these calculations have no physical interest. The Lorentz transformation is devised in order to *preserve* the principle of relativity of motion, and if the mathematical expression of an idea contradicts the idea it is intended to express, it is not the idea that is menaced. There is no reason in this case to suppose that it does, and if it should appear to do so, mathematicians can be left to find their mistake ; it has nothing to do with physics.

Why is it so much more difficult to conceive of the relativity of motion than of that of position ? I think there are at least two reasons. In the first place, the apparent change of size of a rod when it approaches or recedes is a common experience, and the mistake of supposing it to be an actual change would at once have been obvious. But if our experience had normally been confined within a very short range of distance, and then some object had been suddenly removed to a place at which it appeared less than half its customary size, I think the natural assumption would have been that it had actually shrunk. In the case of relativity of motion we are in that position, or even worse. We have not suddenly had experience of the " contraction," but have suddenly become aware of it by calculation. In such circumstances it is not surprising that we tend to think, like FitzGerald, that we have detected a material change.

The second reason is that, by a purely fortuitous circumstance, the expression l/d is also a measure of the angle subtended by the rod at the point of observation, and we therefore automatically describe the effective size of the body as the *angular* size. No one can mistake an angle at his eye for a property of a distant object, so it has been virtually impossible for us to make the error to which the relativity of motion has given rise. This is, of course, in one way a stroke of luck, but it has had the disadvantage that it has led us to regard and to measure the quantity l/d as a whole and so fail to observe the quite separate functions of l and d, the one showing the contribution to the phenomena of the *object* and the other that of its *relation* with something else. That it is indeed a fortuitous circumstance is shown by the fact that it is possible to substitute for d some other

expression of the relation. For instance, we could draw a circle through the ends of the rod and the point of view, and instead of d use the ratio of areas (or some function of it) of the two segments of the circle lying on the two sides of the rod. This, suitably combined with l, would give us the effective size of the rod without introducing the idea of an angle. The analogy with the expression la would then be unobscured by the intrusion of a picturesque but basically irrelevant image.

This problem strikingly illustrates one of the most serious delusions in modern physical science, namely, the misconception (in practice if not in theory) of the relation between mathematics and physics. The Lorentz transformation, or even the Minkowski space-time representation of it, is regarded as the basis of the relativity theory instead of the most convenient means of expressing its requirements. The mathematical symbols are manipulated, usually quite correctly, but without recollection of what they stand for, and consequences are deduced which, notwithstanding that they are obviously incompatible with relativity, are nevertheless claimed to be true because the mathematics is impeccable. The history of the subject is forgotten immediately a formula is arrived at, and the formula is treated as though it were a primitive and eternal logical necessity.

In fact the history of the subject was this. Long experience showed that all known effects of motion were effects of the *relative* motions of bodies, which disappeared when the *relative* motion ceased. To express this fact, physically and mathematically, it was necessary to know whether two clocks at different places were synchronized or not, and there was no natural means of discovering this. An artificial test of synchronization had therefore to be provided, *by definition*, and it had to be chosen so that calculations following from it automatically led to the disappearance of all expectations of physical effects arising from the absolute motion of a single body. Einstein provided such a definition, based on the postulate that the velocity of light was the same in any direction as in its opposite. This was not an *assumption*, which might have been right and might have been wrong. In order to test it you would need separated clocks which were synchronized, and you could not synchronize them without assuming something about the to and fro velocity of light. Your argument would therefore inevitably be circular, so the process of synchronization must be taken as prescribed by voluntary definition, which must stand or fall by its success in preserving the relativity of motion. Accepting it, however, the Lorentz transformation then follows by pure mathematics.

This is the argument in the order in which it is given in Einstein's original paper.* Three years later Minkowski† showed how the Lorentz transformation could be expressed geometrically instead of algebraically, and, being a mathematician who suffered badly from the delusion I have mentioned, he considered it a reproach to mathematicians that the transformation had had to be discovered through physics. But suppose it had been discovered through mathematics ; what would the discovery have been ? Simply that symbols defined in a certain way were related in a certain way, not at all that those symbols had any relation to experience. This could have offered a valuable hint to physicists but it would have had no physical significance at all without the long evidence of experience that all physical effects of motion are effects of relative motion and that Einstein's definition of synchronism gives a consistent expression of this fact. Its physical value depended, *and still depends*, on the absence of a single instance of an effect of absolute motion and of a failure of Einstein's definition to negate expectation of such an effect. Minkowski's oft-quoted statement, that space and time vanish to shadows and only a sort of union of the two remains, is a perfect example of mathematical misconception. What he had shown was that his x and t co-ordinates vanished to shadows, but space and time, regarded as entities, or conceptions, to which the appropriate physical measurements relate, remained as distinct as they had always been, because the operations that gave their measures remained distinct. What had been

* Ann. d. Phys. **17**, 891 (1905)

† Nach. d. K. Ges. d. Wiss. zu Gott. (1900, p. 53)

discovered was that a particular mathematical formula expressed the relation between the measures. If once experience shows a departure from this relation the mathematical formula will be dropped. It will still remain impeccable mathematics, but it will have no physical significance. The " shadows " will suddenly be found to be substantial. And they are no less substantial because their relation still remains expressible by that formula rather than another.

To return to the space-traveller problem. It is, of course, impossible to discuss all the arguments that have been advanced for believing that the traveller will return unduly young, but it will be useful to deal with one general class of them, which finds significance in the fact that the traveller, unlike his earth-bound friend, receives the impulse that causes the separation. This, it is said, introduces an asymmetry between the two men, and the conclusion that their clocks will agree on re-union depends on the relation between them being perfectly symmetrical. There is thus, so it is argued, no violation of the theory of relativity of motion if the clocks are found later to disagree.

The answer to this, of course, is that relativity is concerned with motion,not with the peculiarities of bodies that move, and no matter what causes the separation, the *motions* of the two persons are bound to remain perfectly symmetrical. For every stage in the motion of X with respect to Y, there is an exactly similar stage in the motion of Y with respect to X. It must be so, because motion is essentially of that nature ; otherwise there could be no relativity of motion at all, except by accident in a particular case. You cannot by any contrivance produce a motion in which, say, X is accelerated with respect to Y while Y moves only uniformly with respect to X. Whatever asymmetry may characterize the moving bodies, there is none in the motions, and relativity in this connexion is concerned only with motion.

But the argument is sometimes carried a stage further. It is absurd, so it is said, to ignore the effect of the impulse applied to X, just because the motion it produces can be looked at from different points of view. If one body is subjected to a physical force and the other is not, that body will suffer an effect not experienced by the other. That is perfectly true, but such an effect must depend on the nature of the force, and until that is specified it cannot be calculated. But the argument of those who claim to economize time by space travel never takes any account of this. Whatever be the nature of the force, they say, the effect on the clock will be to retard its rate by the factor a, which is a function only of its uniform velocity while the force is not acting. By what mental process they arrive at this conclusion I cannot imagine. In the case of our metre rods, it is quite conceivable that in the process of changing their relative positions, the one that is displaced may be stretched or compressed, and so may appear different in length from the others when the rods are brought together again. But is it conceivable that that fact can entitle the rod to claim its *angular size* as an intrinsic property, to be retained when the viewpoint which gave it significance is changed for another ? I do not think that anyone who has understood the meaning of relativity could entertain such a notion for one moment.

Another argument seeks to justify the hypothesis of time-saving by appeal to the mathematical mechanism of Einstein's relativity theory of gravitation. According to that theory, the path of a body in a gravitational field is represented as a geodesic in a " space-time " having the properties of a four-dimensional Riemannian manifold, and the " length " of that path measures the proper time occupied by the body in traversing it. There may be more than one geodesic between the same two points, and their " lengths " may differ. Now, it is argued, the space-traveller problem must be considered in these terms, for the necessity for accelerations at the beginning, middle and end of the journey takes it out of the field of the special theory of relativity and into that of the general theory. Hence the proper times of the two clocks will not be the same since they travel along different geodesics, so their readings will differ on reunion.

Before disposing of this it is desirable to

clarify the position regarding the relation of the general to the special theory of relativity, for this is widely misunderstood. The *special* theory of relativity states that all *uniformly moving* coordinate systems are equivalent for the description of laws of nature, " uniformly moving " being defined with reference to the speed of light. The *general* theory of relativity states that *all possible* coordinate systems are equivalent for the description of laws of nature. It is thus a true generalization of the special theory. Neither theory, of course, makes any assertion about what the laws of nature are, but when you have discovered them the theories tell you how to translate them from the terms of one coordinate system into those of another.

We have not yet got very far in the task of formulating laws of nature in terms compatible with the general theory, but in one particular instance there is reason to believe that we have succeeded ; namely, in that of the law of gravitation. Einstein's theory of gravitation is not universally accepted, it is true, but since the argument we are considering assumes it to be valid, we may, without prejudice, assume so too. It is unfortunate that this theory is so often referred to as the general theory of relativity, when it is really a theory of one particular phenomenon which succeeds in satisfying the general theory. This misnomer, among other things, has apparently misled those who advance the argument given above, for the mechanism of the Riemannian manifold is a part of the relativity theory of gravitation, and there is no evidence at all that it is applicable to phenomena other than those of gravitation.* Now whatever device is adopted for projecting our space-traveller away from the Earth, we may say with absolute confidence that it will not be a gravitational field. Hence there is no justification whatever for introducing geodesics in Riemannian manifolds into the problem.

However, let us make a voluntary concession to the advocates of this approach, and allow (without admitting that it is in fact allowable) that the accelerations which the space-traveller experiences can be represented by the gravitational fields that would produce those accelerations. The readings of the clocks will then give the proper times taken in traversing the respective geodesics, and they will differ when the clocks reunite by the difference of those proper times. What sort of difference might we expect ? This argument has been given chiefly by Professors of Mathematics, which is not unnatural since they are likely to be less sensitive than are physicists to considerations of order of magnitude of physical quantities. In an example in which the traveller reaches α Centauri at half the speed of light and returns after 17 years (Earth time), he is estimated to save $2\frac{1}{4}$ years, i.e. about 15 per cent. This is calculated on the assumption that his clock goes slow by the factor α, though what this factor has to do with the effect of a gravitational field or its equivalent is not divulged. Now we know the magnitude of the effect for a gravitational field from Einstein's theory and its verification (if that verification be accepted) in the spectrum displacements shown by white dwarf stars and the Sun. In the case of the Sun, for instance, the displacement is about one in a million. It is easily calculated that an acceleration equal to that of gravity at the surface of the Sun would bring our traveller to half the speed of light in about six days. The four similar accelerations necessary to bring him back to rest on the Earth would therefore occupy about 24 days. We are accordingly asked to believe that an acceleration which, if acting throughout the journey, would produce a retardation of one in a million, will produce a retardation of one in seven when acting for only $\frac{1}{250}$th of the journey.

The argument exemplifies a very common tendency of the mathematically minded when they discuss physical problems. The problem is generalized, and then the whole possibilities of the generalization are read back into the physical situation and regarded as operating there. Because the very slight effects which

* In saying this I am regarding the various suggestions for a " unified field theory," embracing electro-magnetism as well as gravitation, as still *sub judice*.

actual gravitational fields produce can be represented by certain characteristics of a Riemannian manifold, the whole possibilities of any conceivable Riemannian manifold are assumed to have their counterparts in the physical world. By such a process we could prove that pigs have wings. Pigs are members of the animal kingdom ; that kingdom includes winged creatures ; therefore winged pigs exist.

But of course the whole argument in the case of gravitation is based on a complete misunderstanding of the matter. The slowing down of a clock in a gravitational field has nothing to do with *acceleration* ; it is an effect of the physical thing called a *gravitational field*. The atoms in stellar atmospheres whose spectrum displacements reveal it are not moving with the corresponding accelerations; they may not be moving at all with respect to the Earth. To suppose, because a gravitational field causes an acceleration and also a slowing down of a clock, that therefore any acceleration will cause a clock to slow down, is equivalent to supposing, because rain makes yellow grass green again and also wets roofs, that anything that wets roofs will restore the green colour to grass. The spectrum displacement is sometimes misleadingly called a relativity effect, because of the accident that it was predicted by the relativity theory of gravitation before it was discovered. But if observations of a variety of white dwarf stars had been common, and the densities known, before Einstein's theory was constructed, it would have been listed, with the characteristic acceleration, the weights of bodies, and so on, among the typical gravitational phenomena which any theory must explain ; it would not have been associated in any way with phenomena arising from motion. (The Doppler effect, on the other hand, *is* a relativity effect, although it was discovered long before the theory of relativity was thought of. It is an effect of the relative motion of bodies, and not a characteristic of any one of them.) If the general theory of relativity is true, acceleration as such, like uniform motion as such, has no effect on any individual body. It can affect only the relation between bodies, and when that relation is destroyed its effect is destroyed also.

A gravitational field is a physical thing, producing physical effects. It cannot be transformed away, but it can be transformed into an accelerated relative motion. In either case its physical effects remain unchanged, for an accelerated relative motion also is a physical thing. So is a uniform relative motion ; it produces physical effects such as the Doppler effect. It cannot be transformed away, but it can be transformed from the motion of A with respect to B into a motion of B with respect to A. The motion of a single body, A or B, whether uniform or accelerated, *can* be transformed away ; it can be passed on wholly from A to B. Violation of this fact gives rise to such illusions as that of saving time by space travel. The opposite violation—the supposition that *relative* motion can be transformed away—gave rise to kinematical relativity, with its contention that there was no physical difference between an expanding and a static universe.

If this space-traveller controversy leads physicists to the realization that the understanding of physics is as important as blind pushing ahead, it may do good. Mathematics may once more become an aid to reasoning instead of a substitute for it. But if not, the outlook is black indeed.

Postscript

Since this article was written I have received a paper from Mr. Frank S. Crawford, Jr., of the University of California Radiation Laboratory, Berkeley, published by the U.S. Atomic Energy Commission, in which it is claimed that experiments already performed with cosmic ray mu mesons verify " the asymmetric aging predicted by relativity," and it is implied that this requires that the traveller will return younger than his stay-at-home twin. On examination, however, it appears that these experiments relate only to a one-way journey ; they are therefore quite irrelevant. I had already pointed this out (*Nature*, **178**, 680, 1956), and had, in fact, calculated the reading of the traveller's clock on arrival at the star and shown

that it would be behind that of a clock there, synchronized with a terrestrial clock. (*Proc. Phys. Soc.*—in Press), which is all that the experiments described can verify. I had shown further that, notwithstanding this, the two clocks would agree when the traveller returned to the Earth.

Crawford argues that the retardation on arrival at the star can be retained by returning the traveller at a velocity too slow to have any effect on his clock. But the slower he moves, the longer he takes. Reference to my paper will show that when he begins to return his clock becomes *faster* than the Earth clock synchronized for the reverse motion, and you cannot make him lose that advantage slowly without giving him a longer time in which to do it. Crawford wants to make $V \rightarrow 0$ without at the same time making $t \rightarrow \infty$. This vitiates his argument.

It is important to note also that Crawford's result depends on the assumption that while *uniform* motion produces a " time dilation," *accelerated* motion has " no influence on the rate of the clock." It is encouraging to have the latter truth acknowledged, but he is at variance with most commentators, who hold that the accelerations are the determining factors in the matter, and remarkably so with Tolman (*Relativity, Thermodynamics and Cosmology*, p. 194), of whose calculation he speaks approvingly as coming " to the same conclusion." One of the most astonishing and ominous things in this controversy is the variety of inconsistent and mutually stultifying arguments that are put forward, all leading to the same result. It is as though the investigators were more determined to get " the usual result," as one of them puts it, than to examine carefully the route by which they reach it. It is abundantly clear that it is not necessary to accept my version of the matter in order to be convinced of the widespread lack of understanding that exists : that is the dangerous element in the situation.

Forthcoming Institute Meetings

Jan. 11 Manchester and District Branch

In the Bragg Building, University of Manchester, 6.45 p.m.

" *Ferromagnetism and Magnetic Materials* "

MR. A. E. DE BARR, F.Inst.P.
(British Cotton Industry Research Association, Manchester)

Jan. 11 Liverpool and North Wales Branch

In the Department of Electrical Engineering, University of Liverpool, 7 p.m.

" *The Planet Mars* "

PROFESSOR Z. KOPAL
(University of Manchester)

Tea will be served at 6.30 p.m.

Jan. 11 Scottish Branch

In the Regional Physics Department, 9-13 West Graham Street, Glasgow, 7.15 p.m.

" *Silicones and their Applications* "

MR. J. AMES
(Imperial Chemical Industries Ltd., Nobel Division)

Physics and General Education

By NORMAN CLARKE, B.Sc., F.Inst.P.

(*Deputy Secretary, The Institute of Physics*)

It is commonly suggested that the number of students entering the universities of this country to read science is restricted by the marked bias of some headmasters against science on educational grounds. It is said that they regard scientists as technicians—highly skilled technicians, but technicians nevertheless. The bias was described by a public-school science master as "what might be called 'headmaster's prejudice,' in that a scientist in the school is still not considered, generally speaking, as having an educated view, whereas a teacher of modern languages is."

There is little doubt that some headmasters and others do, indeed, hold the view that something vital is lacking in a scientific education—or "training," as they would probably term it. It is also true that, if the number of scientists is to be increased significantly, many boys from public and grammar schools who are capable of obtaining good degrees must be persuaded to read science instead of Arts subjects. It is, therefore, not only on the ground of professional pride but of public policy that we should consider how far the view attributed to those headmasters represents the truth. If we wish to persuade them of their error we should know wherein that error lies. If, on the other hand, their attitude is a justifiable one, then we should recognize that any improved economic position of the country that might result from an increased output of scientists would be dearly bought by reducing the number of adequately educated men. Even if these headmasters are wrong in their ideas of scientific education, they can hardly be blamed for their view. The plea for more able boys and girls to follow courses in science is all too often expressed in purely economic terms. "Industry needs . . ."; "If our country is to survive . . ." and so on. We know the usual exhortations almost by heart. They may be well justified but the appeal is wholly materialistic, even reminiscent of the nineteenth century demand for factory hands. A headmaster who has himself been educated in the humanities may be glad of the extra opportunity that scientific occupations provide for less gifted boys who traditionally would become "something in the City," but he cannot be blamed if he resists an appeal that, because of the manner of its expression, may seem to him to involve the sacrifice of gifted potential classicists and historians to the demands of a materialistic society whose standards he may hold to be both inadequate and distasteful.

C. P. Snow,(1) himself educated as a scientist, wrote recently on the contrast between the culture of the scientist and the "traditional" culture, being himself clearly a "traditionalist." It is a remarkable article, by no means wholly hostile to what Snow calls "scientific culture" but including such comments as: "Sometimes it seems that scientists relish speaking the truth, especially when it is unpleasant"; "They regard it as a major intellectual virtue, to know what not to think about"; and "When you meet the younger rank-and-file of scientists, it often seems that they do not read at all. The prestige of the traditional culture is high enough for some of them to make a gallant shot at it." Dr. Snow, as a Civil Service Commissioner if not as a novelist, has extremely wide contacts among scientists. His comments may or may not be justified, but the point to be emphasized here is that such opinions, from a source with every claim to authority, could not be ignored by a conscientious headmaster, especially if his personal interests already led him to regard a career in the scientific

Civil Service as a tragic waste of any boy with the ability to acquire a " real " education through, say, " Greats."

The issue we should not shirk is whether physics is a discipline fit to be ranked with the humanities as a worthy basis of an education for living. Let us first recognize that disciplines differ in their efficacy in this respect. I strongly agree with Sir Eric James(2) that " the present tendency to equalize all subjects in status and esteem can only rest ultimately upon a profoundly materialistic philosophy. A society which ranks plumbing as an equally valuable study with Greek, since they are both vocational studies for certain occupations (and which should, indeed, rank plumbing more highly, as being more closely ' related to life ') is necessarily one which regards material amenities as equally important with the quality of mental and moral experience which it enables its citizens to enjoy." The question therefore is where physics lies within, or beyond, the spectrum extending from plumbing to Greek.

I shall not venture to give a definition of liberal education, but perhaps I should indicate some of the qualities that I should consider to be among those possessed by an educated man. Dr. F. A. Freeth once said that an educated man was one who found that, on entering a library, his nostrils quivered—a wise comment that might be regarded as a necessary but not sufficient condition. Ability to recognize quality in any field of human interest or activity and the desire to seek it are clearly aims of broad education. Integrity is an obvious requirement. Humility and the preservation of a sense of wonder—these I include, for they are not only Christian virtues but qualities of mind essential alike to the seeking of knowledge and to harmonious social relations. C. P. Snow might level a charge of philistinism, but I should deny any place in true education to the self-conscious cultivation of superficial word-spinning brilliance that often gains transitory acclaim in literary circles. G. K. Chesterton commented on a statement of Oscar Wilde's, that sunsets were not valued because we could not pay for them, with : " Oscar Wilde was wrong ; we can pay for sunsets. We can pay for them by not being Oscar Wilde." The implied sense of obligation and the eschewing of the merely clever, lie at the heart of what I should term education.

The educational value of physics has, of course, been enthusiastically proclaimed. A. W. Barton,(3) headmaster of the City of London School and himself a physicist, has said : " I am convinced that physics with Greek is the finest mental discipline that there is to be found in our school curriculum." In the same article Barton extolled a " liberal " education as an education that would teach a boy " how to live as distinct from merely gaining a living." F. A. Vick,(4) more conservative—and perhaps more realistic—than Barton, believes that " courses in the physical sciences can make contributions to the education of a mind which few other subjects can."

Vick, like Barton, indicates what he means by an educated man—" That he should have a tough and enquiring mind, able and indeed anxious to tackle new problems and new situations . . . really knowledgeable about certain subjects or parts of subjects . . . intellectually honest, able to recognize a hard fact and not afraid to give up preconceived ideas in the face of demonstrable proof . . . he should exhibit the qualities of perseverence and humility and above all of judgement." These qualities of mind and character are essential for the first-rate physicist, but they are also needed by the creative worker in any field of learning. One can, however, go beyond these.

Physics demands the mastery of highly abstract concepts ; neither the advance of physical theory nor the devising of elegant experimental verification is possible without the power of abstract and creative thought. Insight, virile imagination, call it what you will, is essential to good physics. Coulson(5) has put this well : " How disastrously unfortunate it is for the proper understanding of science that it has so frequently been described as if it were a dull deduction from facts . . . when, all the time, practically every advance in science has been the result of a mental leap." Physics is creative

thinking about natural phenomena, whether the physics be pursued in a university or in an industrial laboratory.

However, it may still be urged that such creativeness is developed in or, at least, demonstrated by only the higher flights of research workers. Critics of science may say that to speak of creativeness is extravagant if applied to the generality of graduates, and perhaps especially so if one includes that increasing number of physicists from technical colleges where, it must be confessed, a rather narrow conception of the needs of industry may dominate the courses. By many students, physics courses certainly appear to be valued primarily for their technical content. Although few university students reading history or economics expect to earn their livings as professional historians or economists, most science students intend to and do enter scientific occupations where the technical content of their courses of study is thought by them to be of immediate importance and financial benefit.

I recently received details of a new course in a major technical institution. They begin "The purpose of this course is to train physicists for industrial and government research establishments." There is a later reference to the development of personal qualities, but the impression given is that the course is primarily intended to provide the student with information and skill that will be of practical importance to him in the future. I am not suggesting that this is not an important feature of any course of study, nor that it is absent from any course ; but I do suggest that it is not sufficient as the foundation of a liberal education. The limitations of technical studies are well put by J. L. Montrose[6] : "The dominating characteristic of 'technical education' is dogmatic instruction in existing theories whether of fact or value, or the imparting of information and skills about established techniques and processes . . . instruction in basic sciences, which lie beneath the ideas learnt or the processes assimilated, does not raise the education above the technical level where the object is to ensure better comprehension of the doctrine as doctrine or the technique as technique . . . the degree of intelligence required appears immaterial . . . The difficulty of learning a particular system of beliefs, be it a creed or a philosophy or legal or moral code, does not cause indoctrination to rise above the technical level . . . The technical process of learning results in the student submitting to what he has learnt. He is mastered by his beliefs or by his technique." Instruction or indoctrination of this kind is not what most of us mean by education. It has, of course, been fashionable to declaim that this form of teaching is as valuable educationally as any other ; the prominent industrialists and professional educationalists who take this view nevertheless usually decide that their own sons would fare better in the more rarefied atmospheres of Oxford and Cambridge. Strictly technical education has the peculiar quality of being more advantageous for other people's children.

Montrose distinguishes between technical and specialist education. Of the latter, he says, "It teaches the existing learning of a particular discipline as fully as does a technical study of the subject but proceeds to a higher level by making the student aware of the problems involved in the discipline, of methods developed for dealing with them and of the direction in which thought about the subject is moving."

A high degree of specialization is essential to university education, for it alone can provide what Sir Eric James describes as "a sense of knowledge as a living and growing entity." But I agree with Montrose that a specialist education is not an adequate university education. To quote Sir Eric James[7] again : "We may regard the specialization of some of our university courses with alarm. Superficially, they are little calculated to produce men and women with any very clear idea of the relevance of their subject for social needs, or the very existence of philosophical and moral problems which should be at any rate on the mental horizon of people with their intelligence."

No adequate education can wholly ignore those philosophical problems and questions

that have been sources of speculation throughout human history ; not the least of the claims for physics as a discipline is that the higher flights of the subject itself, relativity and quantum theory being the most obvious examples, impinge on philosophy, metaphysics and epistemology. Barton speaks of the student of Greek as needing " the power to apprehend a general experience of reality." Most advocates of scientific education would urge that here the physical sciences could serve at least as well as dead languages ; but what is the relationship of physics to " reality " ? Again, Barton says that the physicist must have the ability " to appreciate facts." What is a " fact," and what is the relationship of " facts " to " truth " ? What would Vick accept as " demonstrable proof " ? Essential qualities of the physicist might be emphasized if we returned to the old " natural philosophy " as a description of our subject.

We are considering the adequacy of an education in physics as a training for a man who will not only perform a highly technical professional service but will want to move easily among those of his fellows who have been educated in a different way. He will, or should, want to enjoy to the full all that life offers to them and to him. How far anyone carries into his general thinking about life any special qualities and attitudes that are demanded by his specialist study is a matter open to argument. To the extent to which this is ever done, however, an intellectual training in physics that has reached, in some field, a familiarity with the advance of the bounds of physical knowledge may well be expected to develop important qualities of mind and character, among which are integrity, logical reasoning and ability to assess the essentials of problems. These are virtues needed in every department of life. Scepticism, respect for evidence and ability to assess it are highly desirable qualities urgently needed in the consideration of the world's affairs. The physical sciences could produce, as perhaps other disciplines cannot to the same extent, a detestation of cant and prevarication that should be among the attributes of any educated man. It is undue emphasis upon the technical content of physics, from which intellectual speculation and scepticism have been eliminated, that vitiates this argument. A study of physics as a technical or specialist subject, divorced from a philosophical consideration of the relationship between, on the one hand, the data and concepts of physics, and, on the other, the spheres of " reality " not amenable to the methods of physics, can produce in the physicist an intolerance and a dogmatism about " facts " that stultify any contribution by him to the discussion of, and speculation about, literary, aesthetic and spiritual issues. Such a pedestrian attitude to physics is found among some teachers in schools, in technical institutions and in universities.

In the article that I have already quoted, F. A. Vick, while rightly disclaiming that the qualities needed by an educated man can all be acquired from courses in physics, went on to say that " most if not all of them can be developed by contact with some physicists." Here I think that he brings us to the essence of the problem. A physics course is not just the presentation of " facts," " laws " and " theories," despite the inordinate attention that is given by educationalists to the preparation of syllabuses. The vital factor is the teacher. If the teacher regards himself as the purveyor of technical information that will shortly enable his students to devise apparatus and machinery for the better production of refrigerators, television sets or guided missiles, he may well dismiss as irrelevant and even " unscientific " an attitude to the subject that encourages scepticism, tentativeness, speculation and the questioning of authority. Such men are not merely dull, but dangerous. They rely upon authority and dogmatism that are as inhibiting to the true growth of intellectual ability as the dogmatism of mediaeval theology. Students subjected to this type of " education," or rather the acquisition of competence in scientific gadgetry, are likely to emerge with little ability to think about their own subject and with but feeble powers of appreciation of other means of apprehending truth than that which is the province of the physical sciences.

The first-class physicist needs to have unbounded curiosity. He needs to relate by general laws observed phenomena or apprehended truth of different fields of study. He must have the imaginative capacity to formulate hypotheses to guide the next step into the unknown. These are some of the hall-marks of intellectual maturity ; they are qualities that might pre-eminently be inculcated by the study of physics, properly presented by a teacher to whom the growth of physics is a history of intellectual adventure. Somewhere in that study should be implanted a sense of the essential limitations of physical methods, models and theories. The physicist has to be aware that what seem to be the very foundations of his subject may need to be modified or even scrapped in the light of new data or new ways of thinking.

No physicist need doubt the excellencies of his subject as an intellectual training and a foundation for education. How far, though, is a study of physics sufficient to produce the rounded, adequately educated man ? Not very far, if science is an exclusive study. Few of us would wish to be condemned to spend long in the company of men educated only in science or with interests that never transgressed the boundaries of their specialist subjects. Science is no more a complete education than is literature or music or art. All these fields and the interplay of informed and differing opinion about them are part of real education. Science, art, drama, poetry, music, religion are some of the strands that together make our common heritage. Each has helped to shape the world we live in. If education is to be an introduction and guide to our world, each of these fields of human expression must have a place, as must the history of man's thinking about them. What we have a right to ask of scientific education is that, with it as a foundation, we should be able to bring to the other strands of culture a mental vigour and intellectual curiosity that will enhance our own appreciation of them and may enable us to make our own characteristic contribution to their advance.

The value of that characteristic contribution of the scientist can be very great. Especially has this been so in philosophy. Dingle[8] has said that, while the aim of a philosopher is to organize the whole of experience into a rationally connected system, the peculiar characteristic of scientific philosophy is that it, " unlike all previous philosophies . . . does not accept the world of material objects, located and moving in a unique space and time, as a necessary starting point, but goes back to the original experience that led to the conception of that world for practical ends." Experience includes aesthetic and religious experience ; it is unfortunate that there are some who give to the world the impression that the scientist can accept and rationalize only his sensory experience, despite the obvious fact that his life could not be lived with such a view as an exclusive guide.* The physicist, more than most men, should see the force of Dingle's[9] statement that " a religious man has just as much justification for creating a world picture that will interpret his religious experience as the physicist for creating a world picture that will interpret his sensory experience."

Whatever the field of life to which we may turn, experience must precede any attempt to create standards of judgement or a rational system of belief. Part of an adequate education should be the development of perception and appreciation. Perception and appreciation of religious, emotional and aesthetic experiences can best be developed by intimate contact with those of our fellows in whom those powers are already strong. Perhaps, as Vick has suggested, those individuals may be other physicists. But it is a traditional claim that the universities are particularly fitted for the production of educated men because of, and through, a diversity of specialist interest. It is from that diversity that real breadth of experience and

* Eddington, in *The Nature of the Physical World*, wrote : " The materialist who is convinced that all phenomena arise from electrons and quanta and the like, controlled by mathematical formulae, must presumably hold the belief that his wife is a rather elaborate differential equation."

insight into the highest enthusiasms of others are most likely to be acquired. If, for example the student of physics wishes to understand and to share the compelling force of religion as it can be experienced by men of the highest intellectual attainment, he must seek out those who know the truth of religion with what Eddington describes as "a kind of sureness which is very different from cocksureness." From the agnostic or the atheist he will no more learn anything that is valuable in his search than he will learn about physics from the teacher to whom physics is but a pedagogic chore. So it is with other fields of experience that lie outside physics but are rightly held to constitute a proper study for the rounded man.

In this respect I do not see how the disadvantage of the monotechnic institution can be disputed. Some technical colleges and universities have made attempts to create or develop the interests of students in fields other than science or technology by the provision of courses of one or two hours a week in so-called "liberal studies." These are usually lectures on economics, philosophy or literature, and no doubt they have a limited value. Some courses, however, rise no higher than formal instruction in English, perhaps disguised under a title such as "The communication of information." Unfortunately, the justification of such a course may be that some of the students have nothing to communicate. Aesthetic and religious understanding may be conveyed in some small measure by the enthusiast who, in such a situation, has the lonely task of presenting his subject as a more or less formal study to students whose primary interests are in fields that they regard as unrelated to his. Intensity of feeling and of inspiration are likely to burn low in subjects lying outside the specialized interests of the institution, and a deep love of any branch of human study is not easily passed from one individual to another through formal lectures.

In the present-day world, however, the development of cultural interests, whether scientific or otherwise, may seem a trivial pursuit when contrasted with the vital and urgent questions of social responsibility and behaviour. I suspect that some of the "traditional" hostility to scientific education arises from the imagined lack of ethical standards among scientists. The scientist, it is true, should have a personal and immediate sense of concern for these questions. I think that he very often has. Let us ask, however, what are the factors that might influence physicists in deciding one of the most personal problems of behaviour, the fields in which they wish to work, or, perhaps more important, the fields in which they are not willing to work. A very distinguished physicist taking part in a recently televised interview with journalists was asked questions about scientists entering political and similar occupations; he replied by referring to the inherent interest of scientific work, saying "It's such fun." Among the best scientists this is undoubtedly an incentive of great force and in one sense it represents one of the highest urges of the scientist. Rutherford, I am sure, had no greater stimulus than the sheer joy of finding out something new about the workings of nature. But in to-day's world, the scientist with any warmth of human feeling can hardly justify an attitude which implicitly ignores social responsibility and ethical choice. The fact that any adequate bases of that choice and responsibility lie outside the field of physics itself is perhaps the most compelling reason why the world cannot afford to allow he physics student to be narrowly trained as a mere technician.

We may take, by way of example, the work done by German medical scientists on the human "guinea-pigs" who were prisoners in Nazi concentration camps. For all I know, it may have resulted in useful new scientific information. It may even have been scientifically absorbing. But there must be very few scientists who would justify such work, either on the ground of the acquisition of new knowledge or of "fun."

On what basis, then, do we profess to condemn it? And is it a basis that we take care to present to science students as a guide to their own behaviour? Not without reason, our fellow men fear some of the

spectacular triumphs of applied research. What the scientist is perhaps less aware of is that men fear the scientist himself. Aldous Huxley[10] was expressing a common view when he wrote : " Thanks to the genius and co-operative industry of highly trained physicists, chemists, metallurgists and mechanical inventors, tyrants are able to dragoon larger numbers of people more effectively and strategists can kill and destroy more indiscriminately and at greater distances than ever before. On many fronts nature has been conquered ; but, as Tolstoy foresaw, man and his liberties have sustained a succession of defeats." Yet my own impression is that the older scientists of the present day have made greater and more successful efforts than the members of other academic or occupational groups to formulate for themselves a working philosophy for living, and to bring public attention to bear on some of the problems with which the world is faced.*

The critical problems created by our newly won ability to control our environment, which lie behind much of the " traditional " suspicion of and hostility to science, are problems not of power and knowledge but of behaviour. The emergence of enormously enhanced power from the results of scientific research has created new opportunities but the problems are new only in scale, not in kind. The problems are age-old ones of human judgement, choice and decision, but the new situation throws into sickeningly clear perspective the ethical bankruptcy of our society. But in the decisions of public policy that have largely shaped the post-war world, scientists have had very little influence indeed. It is usually forgotten by the critics of the scientist that the decisions that have led to a world dominated by fear and uncertainty, decisions involving ethical choice and behaviour, have been taken by " traditionalists." We may doubt whether scientists would have behaved differently, but, on the showing of recent history, if any culture has failed to meet man's need, it is the culture for which Snow nostalgically yearns. It appears to have proved singularly inadequate as a guide to responsible choice.

Many of our young scientists undoubtedly seem to lack any recognizable moral standards ; some of them appear to regard education, for example, as nothing more than a means of acquiring academic status that will in turn lead to economic advantage. I do not know how they would find any basis from which to criticize Hitler's obedient medical and scientific technicians who knew no limitations upon the ends to which their knowledge might be put. In this, however, do scientists differ significantly from graduates in the humanities ? May not the fault lie primarily within our schools and universities, not all of which consider it to be part of their responsibility to indicate to students how a basis for value-judgements may be reached ? In a book that is perhaps one of the most important to appear since the last war, Sir Walter Moberley[11] says: " Most students go through our universities without ever having been forced to exercise their minds on the issues which are really momentous. . . . Owing to the prevailing fragmentation of studies, they are not challenged to decide responsibility on a life purpose or equipped to make such a decision wisely. They are not incited to disentangle and examine critically the assumptions and emotional attitudes underlying the particular studies they pursue, the profession for which they are preparing, the ethical judgements they are accustomed to make and the political or religious convictions they hold. Fundamentally they are uneducated." Or again,[12] " If you want a bomb the chemistry department would teach you how to make it, if you want a cathedral the department of architecture would teach you how to build it, if you want a healthy body the departments of physiology and medicine would teach you how to tend it. But when you ask whether and why you should want bombs or cathedrals or healthy bodies the university, on this view, must be content to be dumb and impotent. It can give help and guidance in

* The American *Bulletin of the Atomic Scientists* is a notable example of responsible discussion by scientists of vital current problems.

all things subsidiary but not in the attainment of the one thing needful. In living their lives the young are left 'the sport of every random gust.' But for the educator this is abdication." So long as some universities and schools are content to train rather than to educate, so long as technical competence can be applauded even when wedded to irresponsibility, so long as a student can be indifferent to ethics and philosophy unless they should form part of his purely specialist study, so long may the world expect to move from crisis to crisis. As Moberley says[13]: "It is a fallacy to suppose that by omitting a subject you teach nothing about it. On the contrary you teach that it is to be omitted, and that it is therefore a matter of secondary importance. And you teach this not openly and explicitly, which would invite criticism; you simply take it for granted and thereby insinuate it silently, insidiously, and all but irresistibly." The subjects that are omitted are those that might give a student a basis for choice and a power over himself; the subjects that are taught and emphasized give him only power over his environment and over other men. Rounded education must again become the main concern of the universities, as many university teachers recognize.

To the re-creation of a practical philosophy and moral code by which men can live, the scientific mind can make a great contribution. A scientific attitude does not imply conformity to a "scientific" code of behaviour or belief. Specialist education can, no doubt, significantly influence one's viewpoint and standards, particularly, perhaps, one's criteria of credibility, and the attitude of mind thereby created may profoundly affect one's interpretation of experience. Yet men's experience of life and their capacity for experience vary so markedly that differences of opinion and belief are inevitable. It is surely good that this should be so. Nevertheless, one could hope that adequately educated men, and perhaps particularly those educated in the discipline of science, would have certain common standards. In politics, for example, one might hope that a scientific mind would be receptive to truth from whatever quarter it might come, but that a claim to truth would be critically tested. One could also hope that the scientist would know what he meant by words, including difficult and emotionally charged words such as "freedom," "peace" and "defence," and that their meanings would not be modified to conform to personal or party loyalties. The integrity that we claim as an essential of true science should know no compromise with political sophistry.*

The test of all that is claimed for scientific education does not lie in its effectiveness in resolving purely technical problems. The value of any education is to be measured by its universality, by its relevance to the solution of human difficulties and the enhancing of human joys. The opponents of increased scientific education sometimes write and talk as though scientists were the willing architects of an Orwellian future. The dangers of drifting towards such a grim situation are obvious enough, but I believe that, at its best, scientific education can be a potent force directed towards a saner world. If, in fact, scientists can display in the wider aspects of life the qualities which it is plausible to claim can be inculcated by a scientific education, and if they can have the humility to recognize that other men differently educated can contribute other aspects of truth to the community's life, we may be

* Many "traditionalists" accept as self-evident the quaint belief that most physicists tend towards communism or fellow-travelling. Lewis and Maude, in *The English Middle Classes* (1949), say categorically: "The political temper of scientists is almost occupationally left-wing" (p. 164). In the Penguin edition (1953), however, this is changed to: "The political temper of scientists has been thought to be almost occupationally left-wing: but in 1956 *Tribune* published letters from some of them confessing their preference for working in capitalist industrial firms" (p. 126). It is interesting to note the nature and weight of the evidence that can require these authors to modify what was presumably a considered judgement based on evidence. C. P. Snow, in the article already quoted, advances, as though evidence were unnecessary, the grotesque statement: "A very high proportion of engineers is almost as conservative as doctors; of pure scientists, the same would apply to chemists. It is only among physicists and biologists that one finds the Left in strength."

able to make some advance to a society which is, in Bertrand Russell's words,(14) " not apologetic towards dogmatisms of the right or left, but deeply persuaded of the value of liberty, scientific freedom and mutual forbearance." " For without these beliefs," Russell continues, " life on our politically divided but technically unified planet will hardly continue to be possible."

REFERENCES

1. C. P. Snow. *New Statesman and Nation*, October 6, 1956, p. 413.
2. E. J. F. James. *An essay on the content of education*, Harrap (1949), p.58.
3. A. W. Barton. *Bulletin of The Institute of Physics*, **6** (1955), p. 151.
4. F. A. Vick. *Bulletin of The Institute of Physics*, **6** (1955), p. 143.
5. C. A. Coulson. *Science and Christian Belief*, Oxford University Press (1955), p. 49.
6. J. L. Montrose. *Universities Quarterly*, **7** (1952), p. 70.
7. *An essay on the content of education*, p. 85.
8. H. Dingle. *The Scientific Adventure*, Sir Isaac Pitman & Sons Ltd. (1952), p. 203.
9. *The Scientific Adventure*, p. 359.
10. A. Huxley. *Science, Liberty and Peace*, Chatto and Windus (1947), p. 6.
11. Sir Walter Moberley. *The Crisis in the University*, S.C.M. Press Ltd. (1949), p. 70.
12. *The Crisis in the University*, p. 52.
13. *The Crisis in the University*, p. 56.
14. Bertrand Russell. *Philosophy and Politics*, Cambridge University Press (1947), p. 27.

Sir Ifor Evans, Provost of University College, London, writes that the College authorities wish to " make contact with old students of University College, London, of whom we calculate there must be some 30,000 either in this country or overseas. Unfortunately, we have got records of the careers and up-to-date addresses of only a very small proportion of this number. The College authorities are anxious to get in touch with old students, to invite them when possible to appropriate College functions, and on occasion to seek their advice. It is only when some honour, public appearance or other matter is recorded in the press that the College can add to its records of the individual concerned.

The College authorities hope that old students will write, even just a postcard, to the Secretary of University College, London, Gower Street, London, W.C.1, giving their addresses, dates at College, and subjects studied, and will keep the Secretary informed of changes of address."

Vol. 7, December, 1956

The Parsons and Marine Engineering Turbine Research and Development Association

By T. W. F. BROWN, D.Sc., S.M., F.Inst.P.
(*Research Director*)

INTRODUCTION

The Parsons and Marine Engineering Turbine Research and Development Association (known by its initials Pametrada) was formed in May, 1944, to carry out research and development work on turbine machinery for ship propulsion. It is a co-operative research association, owned and controlled by the leading British marine turbine building firms.

The name Parsons in the title commemorates the work of Sir Charles Parsons, who first applied the steam turbine to marine propulsion, and who played such a large part in its subsequent development. One of the earliest dates one associates with Parsons's work is 1897, when his turbine-engined yacht "Turbinia" demonstrated its then remarkable turn of speed at the annual Naval Review. Parsons was able to show that the steam turbine had the advantages of compactness and light weight, smoothness of running and high efficiency (particularly for higher powers), and as a result from about 1905 practically all Naval vessels, passenger liners and high-powered merchant ships have been turbine-driven. The introduction of the marine oil engine in 1910 has had little effect on the predominant position of the steam turbine in ships of this class.

It clearly follows that for a maritime nation such as ours, the development of marine turbine machinery of high efficiency and performance is a matter of the utmost importance. Although the development of the marine turbine has been continuous since its first introduction, it was realized by the industry that modern developments (including the introduction of the gas turbine), and the increasing use of scientific knowledge, made desirable the formation of a central organization for research and development work, to serve the marine industry as a whole, and to assist it in maintaining its continuous progress. These were considerations which led in 1944 to the formation of Pametrada.

The functions of the new Association, as laid down at the time of its formation, are, briefly, to initiate and carry out research for the improvement and development of steam and gas turbines for marine propulsion, with all their associated and auxiliary equipment; to carry out full-scale tests of turbine installations; to set up standards of fit and finish required in the principal components of turbine machinery; and to advise member firms in all matters associated with the design and layout of marine turbines and reduction gearing.

HISTORY AND ORGANIZATION

These very broad terms of reference demanded the setting up of extensive research and testing facilities, in addition to the building up of a suitable design team. The writer was appointed Research Director in September, 1944, and the recruitment of staff and the planning of the permanent buildings and equipment commenced at that time. The lease of a valuable riverside site on the Tyne at Wallsend was acquired, and constructional work started in May, 1945. From the long-term standpoint the absence of buildings on the site was advantageous, since it was possible to plan the whole of the Research Station from the beginning, instead of converting existing premises. Temporary office accommodation was obtained in Wallsend, and Pametrada's first designs were in fact produced in a local inn, where some of the offices were situated.

The main office building and the first of the test houses were ready for use by mid 1946. From that time the growth of the Association has been rapid. Ownership of the original property and adjoining land has since been acquired, giving a site of 35 acres, with ample room for expansion. At present prices the value of the buildings and equipment exceeds £1,000,000. The total number of staff is now 344, including 66 graduates.

Pametrada is financed by contributions from its twenty member firms, supplemented by grants from the Department of Scientific and Industrial Research and by fees for specific services, such as the preparation of designs, special investigations made at the request of member firms, or researches carried out under contract. Control is vested in a Council drawn from the senior directors of the member firms, together with two non-voting members appointed by D.S.I.R. While maintaining close contact with D.S.I.R. the Association thus remains fully autonomous.

Technical policy is controlled by a Research Board acting through five technical committees, which deal respectively with Steam Turbines, Gas Turbines, Transmission, Materials, and Naval Designs. The Research Board and its committees are drawn from the senior technical staffs of the member firms and from other interested bodies. In this way it is ensured that the researches carried out are closely linked with the needs of the marine turbine building firms, and that the fullest use is made of the knowledge and experience available in the industry.

With regard to internal organization, there are three main departments, dealing respectively with Design, Research and Full-Scale Testing, and these are served by the Drawing Office, the Secretarial and Accounts Department, and the Library and Information Section.

The heads of these six departments are responsible directly to the Research Director, but this is chiefly for the purpose of administrative control and there is a very free interchange of information about each other's work between the heads of departments on a day-to-day basis.

Design Department

Any account of the activities of Pametrada should draw attention to the key position occupied by the Design Department, providing as it does a vital link between research and application. As will be seen, the results of the Association's researches are made available not only in research reports, but are also built into the designs which are prepared.

The Design Department prepares the tendering particulars for geared turbine machinery for the Association's member firms, and in the event of an order being placed collaborates with the firm concerned in the detailed design of the machinery to any extent that may be desired. In addition to the design of the main machinery it also advises, when requested to do so, on all questions relating to feed-heating cycles, boilers and auxiliaries.

Representatives from the Design Department attend acceptance trials of completed ships, and may be called upon to investigate cases of hull and engine vibration, loss of power, mal-operation, and so on.

The extent of this work may be judged from the fact that a total of 97 design inquiries were dealt with in 1955. Pametrada designs of machinery in service have now reached a total of 2,500,000 S.H.P. and include vessels ranging from cross-channel steamers, such as "Normannia" and "Brighton," to large passenger vessels such as "Caronia," "Chusan," "Southern Cross" and "Empress of Britain."

In the early days most of the designs produced were of the orthodox Parsons type, but the Association soon began the development of its own designs. For example, it is nine years since the first impulse turbine designed at Pametrada went into service, and over 50 turbines of this type are now in successful operation. It is particularly gratifying to the designers that no case of blade vibration failure has been reported throughout this period, for the safeguarding of blades against vibration has been a fundamental feature of these designs.

A growing number of inquiries is being received from marine engineering firms in other countries for licences to build turbines

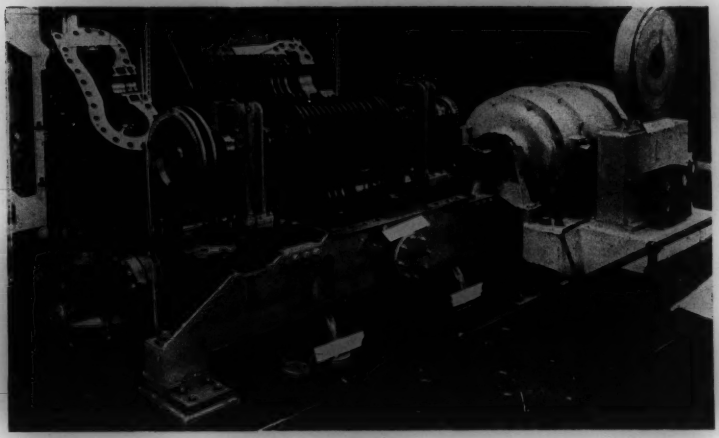

FIG. 1.
Double-casing high-pressure turbine opened up for inspection on test bed.

to the Association's designs. So far licences have been granted to five companies in Holland and one in Canada. All income from this source is ploughed back into research, for the Association is strictly non-profit-making.

The above remarks relate to steam turbine machinery, but additionally a programme of gas turbine research and development is being actively pursued. In 1946 the complete working drawings were produced of a 3,500 S.H.P. marine gas turbine, complete with manoeuvring couplings and speed reduction gear to operate at 85 r.p.m. main-shaft speed. This was among the first gas turbines designed for marine use and to drive the propeller directly. Economy and reliability are of prime importance in a ship, and the designers therefore provided for a life exceeding 100,000 hours, which is the equivalent of 20 years' running. After 100 hours' continuous run in 1952 the gas turbine was inspected by Lloyd's and given a very satisfactory report. The actual fuel consumption of the installation proved to be appreciably lower than the designed consumption as originally conceived.

The development of a liquid-cooled gas turbine operating at very high gas temperatures (of the order of 2,200°F.) is being pursued, and a single-stage experimental unit designed for this temperature is undergoing preliminary tests in the Research Department.

The gas turbine section of the Design Department has dealt with a number of design inquiries for gas turbine machinery, and the design of one installation, for a power of 6,400 S.H.P., has been carried to an advanced stage.

Turning to gearing design, apart from design inquiries for reduction-gear units, designs have been prepared for improved types of turning gear, and also for a hydro-centrifugally-operated friction clutch for incorporation in the Pametrada hydraulic reversing gear. The clutch ensures non-slip drive when running ahead.

Research Department

The Research Department is by far the largest of the departments, and is organized in eight sections, each under a section leader. Each section may contain up to eight or ten graduates, together with, where necessary, test engineers, computors, and laboratory assistants. The workshops and the instrument section are also included in the Research Department for administrative purposes.

The work of the Department covers a wide and varied field, extending from full-scale tests of machinery components to research into the lubrication of gears and bearings, from the design of complete fuel systems for gas turbines to the study of corrosion problems, and from vibration analysis to the development of high-temperature materials. Pametrada is well equipped to undertake both fundamental research and *ad hoc* investigations on all types of problem within its comprehensive scope.

Large-scale work requiring steam-driven test rigs is carried out in a test house equipped with a boiler which can supply 40,000 lb. of steam per hour at a pressure of 1,200 lb. per sq. inch, and a temperature of 950°F. A second-stage superheater, separately fired, enables the steam temperature to be raised to 1,100°F. A second boiler of about the same capacity supplies steam at 250 lb. per sq. inch. Apparatus at present in use in this building includes, amongst other items, a steam turbine undergoing tests at high temperatures to check design features and materials, several gearing test rigs for determining gearing performance and the factors affecting gear failure, apparatus for work on journal and thrust bearing behaviour, and a rig for measuring the performance of hydraulic and flexible couplings.

There is also a small-scale Mechanical Laboratory in which theories can be given preliminary tests at minimum cost.

Of vital importance in the development of both steam and gas turbines is research into the fundamentals of fluid flow. In the Aerodynamic Laboratory this work is carried out using models, with air as the working fluid. By operating at the correct Mach and Reynolds numbers exact similarity is obtained with the flow in full-scale turbine parts. The aerodynamic equipment includes both low-pressure and high-pressure air test plant, the latter including a variable-density wind tunnel in which speeds of up to Mach 3 can be obtained.

Facilities for testing gas-turbine combus-

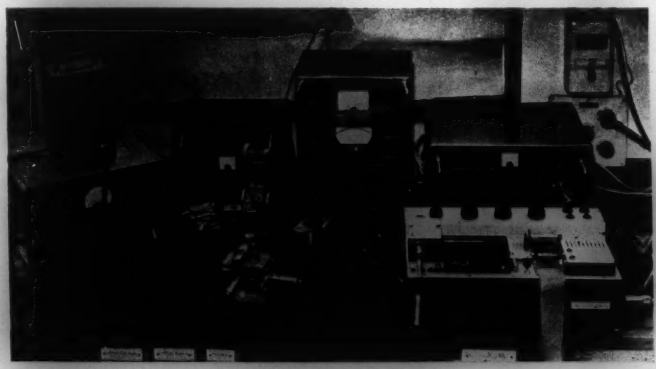

FIG. 2.

Laboratory investigation of modes of blade vibration including the measurement of amplitude and damping factors.

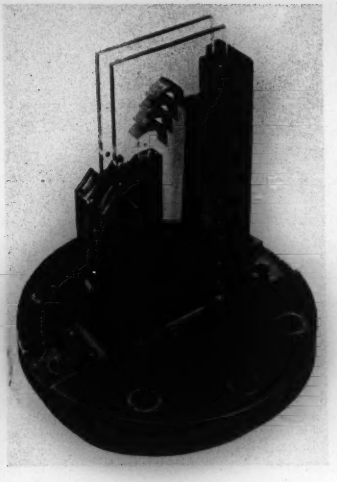

FIG. 3.
Cascade of turbine blades for supersonic flow investigation.

tion chambers and heat exchangers are available in the heat transfer and combustion laboratory, which also contains a sprayer laboratory, equipped with apparatus for the measurement of sprayer output and the examination of spray patterns.

Basic to all the Association's work is accurate instrumentation, and the calibration, fitting, and maintenance of instruments used on research schemes is the responsibility of a separate section.

The Electronics Laboratory is concerned mainly with the development of electronic instruments required for special investigations, particularly in the field of vibration measurement and analysis. Some of the instruments designed by this section are now being manufactured under licence by commercial firms.

The Association's scientific resources also include well-equipped laboratories for applied physics (including acoustics), chemistry and metallurgical research on engineering problems.

Full-Scale Trials Department

From the beginning, one of the most important of the Association's activities has been the conducting of full-scale trials of marine turbine machinery. Until the formation of Pametrada no facilities had existed ashore for the testing of prototype machinery of high power. Numerous trials had been made at sea over the years, but owing to wind and weather the conditions for steady running had rarely been present. Moreover, trials at sea are restricted both by the time factor and by the impossibility of replacing any item not proving entirely satisfactory. The very fact that no item can be accepted for use at sea unless it is certain to give reasonable satisfaction limits the scope for tests in ships, and tends to lead to an unduly conservative policy in design.

The establishment of shore-testing facilities at Pametrada has enabled the development of new machinery to be considerably speeded up. The main machinery trials building has been specially designed for such work. The test bed is 83 feet long by 21 ft. 8 inches wide, and the permanent equipment includes a hydraulic dynamometer capable of absorbing outputs of up to 60,000 S.H.P. at speeds between 160 and 380 r.p.m. The trials of each set of steam turbine machinery so far tested have extended well over a year, with intervals for modification and replacement. Although the majority of this work has been on Naval machinery, merchant-ship machinery has not been neglected. A double-casing steam turbine unit for a merchant ship, using steam at 950°F, has recently completed its trials.

In all this work the Trials Department is in the position of being able to call in at any stage specialists from the Research Department either to make special measurements or to collaborate in the solution of particular problems. This might involve, for example, chemical analysis of lubricating oil or feed water (in addition to the usual routine tests) metallurgical examination of failures, or corrosion, the measurement of gear tooth scuffing or pitting, recording and analysis of machinery noise and vibration, the produc-

FIG. 4.
Assembly of single-stage experimental air turbine and dynamatic brake.

tion of special-purpose electronic instruments, and so on.

In addition to steam turbine machinery trials the Trials Department has also been responsible for the testing of the 3,500 S.H.P. gas turbine which was developed by the Association and constructed by the member firms, and which was mentioned in connection with the work of the Design Department. After completion of the initial development and performance tests this unit has been used primarily as a research tool, for example, for work on the combustion of residual fuels and the associated problems of corrosion and fouling of turbine blades.

CONCLUSION

It will be seen from this necessarily very brief survey that the work in progress at Pametrada is varied in character, and covers a range of activities from tests of a practical engineering kind to fundamental research. In the limited space available it has not been possible to do more than indicate in a general way the kinds of problems which are dealt with. Many of the problems that occur are in the rather indeterminate region between physics and engineering, in which the contribution of the physicist can be invaluable.

It can be inferred from the speed with which Pametrada has grown that it is fulfilling an important need, and that the general atmosphere is one of continuous progress. The results of the work go to improve the efficiency of an industry which will always be of vital importance to the country.

Vol. 7, December, 1956

The Institute's Journals

PRINCIPAL CONTENTS OF THE DECEMBER, 1956, ISSUES

Journal of Scientific Instruments: Volume 33, No. 12

SPECIAL ARTICLE

Some principles of measurement and control. By J. F. Coales, F.Inst.P. (*Department of Engineering, University of Cambridge*).

Measurements can be divided into two broad classes : those which only have to be observed and recorded and those which are used to control sources of power in order to change some quantity such as position, speed, temperature or pressure. In both cases the principles are the same and there are certain limitations from which all measuring instruments suffer, e.g. they all disturb the physical system on which the measurements are being made and they all have inertia and damping to some degree. Also, no measuring instrument is completely stable and all exhibit unwanted fluctuations if the sensitivity is increased to the limit of usefulness.

In the paper these limitations are discussed together with the principles underlying the design of measuring systems to reduce their effect to a minimum. The simple theory of linear control systems is developed and it is shown that the only real difference between measuring systems and control systems lies in the magnitude of the power required at the output. Negative feed-back in a closed-loop system is shown to be the equivalent of the restoring force in an open-loop system.

ORIGINAL CONTRIBUTIONS

A new vacuum plate-camera of large capacity. By L. N. D. Lucas, F.Inst.P., and P. B. Sewell (*Physics Department, University of Western Australia, Nedlands, Western Australia*).

A multiple-plate vacuum camera for use in vertical-column type electron optical apparatus is described. The camera incorporates a new method of plate storage and selection which is very reliable in operation and makes large capacity and good pumping characteristics compatible with small volume. Design details are given for a camera of 4 litres free volume with a capacity of up to twenty-four 3¼ × 4¼ in. photographic plates.

An automatic analyser of uranium content in process streams. By H. Bisby and L. H. Brown (*Atomic Energy Research Establishment, Harwell, Berks*), and D. R. Chapman, Grad.Inst.P. (*Baird and Tatlock (London) Ltd., Chadwell Heath, Essex*).

The instruments described employ an absorptiometric technique for the determination of uranium-ion concentrations in aqueous solutions. Contemporary batch samples are taken in cyclic order from process streams, separately treated with aqueous ammonium thiocyanate, and the resulting colour complexes are analysed by an ultra-violet absorptiometer at 3650 Å. The cycle of events is entirely automatic and a permanent record of the uranium-ion concentration of the individual streams is produced. A four-point general-purpose analyser and a sixteen-point analyser for low (0·005 g/l.) concentrations of uranium are described in detail. The instrumental techniques evolved have wider applications in automatic chemical analysis.

On the reduction of the dark current of photomultipliers. By Zs. Náray (*Central Research Institute for Physics, Budapest*).

Two methods are used for reducing the rate of dark current pulses of photomultipliers ; the reduction is equivalent to a cooling of about 100° C. The two methods are : the reduction of the sensitive area of the photocathode and the application of a suitable shield potential to a layer on the outer surface of the envelope.

In the course of the investigation of the shield effect the stability conditions of the multiplier and the effect of the shield potential on the pulse height distribution were studied.

A Kösters-type interferometer. By C. F. Bruce, F.Inst.P. (*Division of Metrology, National Standards Laboratory, Commonwealth Scientific and Industrial Research Organization, Sydney, Australia*).

The design and performance are described of a Kösters-type interferometer which measures lengths of up to 500 mm directly by interferometry. Isotopic light sources are necessary for the measurement of the longer lengths, and sources containing mercury 198 and krypton 86, as well as natural krypton and

cadmium, have been used with this interferometer. Results of some length and relative wavelength measurements are given, to illustrate the performance of the interferometer operating in air and *in vacuo*.

A simple direction-sensitive phototransistor circuit for use in optical pulse-counting systems. By W. T. Bane and D. L. A. Barber (*National Physical Laboratory, Teddington, Middlesex*).

A current technique for measuring digitally the angular position of a shaft involves counting pulses generated by the interruption of a beam of light falling on two photocells by a serrated disk mounted on the shaft.
A very simple phototransistor circuit is described which detects the passage of a serration and provides an output pulse on one of two lines, according to the direction of rotation, so that an electronic counter can be made to change its count accordingly. The circuit can be used with other, similar techniques for linear measurement and may be modified for counting interference fringes or moiré fringes.

A simple method for the measurement of high resistance values. By A. E. Hawkins, A.Inst.P. (*Department of Physiology, Royal Veterinary College, University of London*).

A modified Wheatstone network is described for the measurement of resistance values up to $10^9\,\Omega$. The accuracy is better than $\pm 2\%$.

Precision measurement of small radii of curvature. By R. N. Wilson (*National Physical Laboratory, Teddington, Middlesex*).

The conditions for the accurate measurement of small radii of curvature by microscope methods are discussed and the relevant formulae stated.

An improved ionization gauge control circuit. By P. Hariharan, A.Inst.P., and M. S. Bhalla (*National Physical Laboratory of India, New Delhi, India*).

In this unit, the heating power for the ionization gauge filament is supplied by an audio amplifier fed from an internal oscillator. Stabilization of the electron current, for wide variations in the emissive characteristics of the filament, is achieved by a negative feedback loop which controls the gain of the amplifier. Ion currents ranging from 100 to $0{\cdot}01\,\mu A$ are read on a single logarithmic scale by utilizing the retarding field characteristics of a triode. This eliminates range switching and is particularly advantageous for multi-point reading or continuous recording of pressures.

A double-beam microspectrometer. By G. H. Haggis (*Middlesex Hospital Medical School, London, W.1*)

A modified single-beam spectrometer, fitted with a small rocking mirror to provide a double-beam through a reflecting microscope, is described. The ratio of the intensities of the two beams is determined electronically, and fed through to a pen recorder. The merits of this arrangement are compared with those of the other micro-double-beam systems.

Temperature cycle controller. By J. C. Barnes (*Radio and Electrical Engineering Division, National Research Council, Ottawa, Canada*).

A description is given of an instrument suitable for use in research laboratories where process time-temperature requirements may be extremely varied and where simplicity of cam layout is therefore of prime importance.

Measurement of the optical density of smoke in a chimney. By A. Littlewood (*Fuel Research Station, London, S.E.10*).

An instrument is described for recording the optical density of smoke in a chimney. It was designed for the study of smoke emission from domestic-heating equipment at the Fuel Research Station, and its readings are independent of changes in the characteristics of the components and of variations in the electricity power supply. This is achieved by using a double-beam, null-balancing system with a single light source and a single barrier-layer photoelectric cell.

A mechanical Gardner mobilometer. By J. E. Roberts, A.Inst.P., A. J. Taylor and D. E. Woods (*Armament Research and Development Establishment, Fort Halstead, Kent*).

A mechanical counterpart of the Gardner mobilometer is described which gives results in agreement with those obtained on the hand-operated instrument and enables the rate of testing to be increased to sixteen determinations per hour.

The generation of accurate cylinders. By D. A. Davies (*Division of Industrial Chemistry, Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia*).

A method of diamond-turning accurate cylinders for the production of helical rulings is described. Details are given of the special tool holder, and performance figures quoted show that, for a typical cylinder, the central half may be held constant in diameter to $\pm 10\mu$ in.

LABORATORY AND WORKSHOP NOTES
NOTES AND NEWS
NEW INSTRUMENTS, MATERIALS AND TOOLS
MANUFACTURERS' PUBLICATIONS
NOTES AND COMMENTS

Vol. 7, December, 1956

British Journal of Applied Physics: Volume 7, No. 12

CONFERENCE REPORT

Summarized proceedings of a conference on low temperature crystallography—Oxford, April, 1956.

A joint conference of the X-ray Analysis Group of The Institute of Physics, and the Low Temperature Group of the Physical Society, was held at the Clarendon Laboratory, Oxford, on April 12 and 13, 1956. The theme included the study of structure and associated properties at low temperature, phase transitions, specific heat, thermal vibrations and absorption spectra, in both theoretical and experimental aspects.

ORIGINAL CONTRIBUTIONS

A photoelastic method employing scattered light for the solution of plane stress problems. By W. Shelson (*The Hydro-Electric Power Commission of Ontario, Toronto*) and I. W. Smith (*University of Toronto, Canada*).

A new photoelastic method for the determination of the individual principal stresses in two-dimensional problems is described. The method is based on the combined use of three retardation fringe patterns—a standard isochromatic pattern and two perpendicular scattered light patterns.

Flying spot counting and sizing of non-uniform particles. By H. W. Loeb, A.Inst.P. (*Hivac Ltd., Harrow, Middlesex*).

A modified scanning principle involving a variable speed of scan is described which permits the extension of applicability of flying spot methods to particles, such as bubbles or droplets, characterized by a non-uniform degree of interception of the scanning beam.

The elastic properties of dilute aqueous gels. By L. J. Hastewell and R. Roscoe, A.Inst.P. (*Physics Department, King's College, Newcastle upon Tyne*).

A study of elastic behaviour under shear stress below the yield value has been made on seven different gels covering a wide range of chemical constitution. The static rigidity of a gelatine gel was found to increase with temperature in accordance with the kinetic theory of elasticity for long-chain polymers, and a similar variation was found in the case of a bentonite gel. This suggests that even when the material dispersed in a gel consists of discrete particles a loose chain structure is formed which is mechanically similar to that existing in a polymer gel. The theory of elastic loss for solid cross-linked polymers developed by Kirkwood would thus appear to be applicable to these gels. This has been tested by a series of measurements on the dynamic rigidity and dynamic viscosity of all seven gels together with observations of their creep and static rigidity. In four cases the results are consistent with this theory, but in the others it appears that the spectrum of retardation times is broader than the theoretical spectrum.

Viscosity and action. By T. V. Starkey, F.Inst.P. (*The Technical College of Monmouthshire, Crumlin, Mon.*).

Hamilton's principle is used to show that for the laminar flow of a given volume of liquid through a tube the product of the energy dissipated and the time is a minimum. This condition requires a parabolic velocity distribution in laminar flow through tubes. It is also shown that the non-turbulent flow of a fluid showing shear dependence is not laminar, and that it resembles in many fundamental respects the turbulent flow of a Newtonian liquid. These results follow from the recognition of apparent viscosity as a direct measure of the action per unit volume associated with a given change in the configuration of the elements of which the fluid may be imagined to consist.

Vibrations of an end-loaded strip. By H. S. C. Chen (*Johns Hopkins University, Baltimore, Maryland, U.S.A.*).

The problem of an end-loaded strip, vibrating in a vertical plane, has been solved under the usual condition that the mass of the strip is neglected. The deflexion curve is derived first from statical considerations. Frequency is then calculated on the basis of energy relations. Agreement with experiments of Hearmon and Adams seems to be better than previous results.

NOTES AND NEWS

CORRESPONDENCE

The application of the centripetal effect in air to the design of a pump.
From B. Popper *and* M. Reiner.

Corner fractures in explosively loaded thin-walled steel cylinders.
From S. Singh.

NEW BOOKS

NOTES AND COMMENTS